

$H^\pm W^\mp$ production in the MSSM at the LHC

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Abstract. We investigate the viability of observing charged Higgs bosons (H^\pm) produced in association with W bosons at the CERN Large Hadron Collider, using the leptonic decay $H^+ \rightarrow \tau^+ \nu_\tau$ and hadronic W decay, within the Minimal Supersymmetric Standard Model. Performing a parton level study we show how the irreducible Standard Model background from $W + 2$ jets can be controlled by applying appropriate cuts. In the standard m_h^{\max} scenario we find a viable signal for large $\tan\beta$ and intermediate H^\pm masses ($\sim m_t$).

The quest for understanding electroweak symmetry breaking and mass generation is one of the driving forces behind the upcoming experiments at the CERN Large Hadron Collider (LHC). In the Minimal Supersymmetric Standard Model (MSSM), which is a two Higgs Doublet Model (2HDM) of type II, the Higgs sector consists of three neutral and one charged Higgs bosons after electroweak symmetry breaking. The charged Higgs boson (H^\pm) is of special interest since its discovery would constitute an indisputable proof of physics beyond the Standard Model.

The main production mode of charged Higgs bosons at hadron colliders is in association with top quarks through the $gb \rightarrow H^- t$ and $gg \rightarrow H^- t\bar{b}$ processes [1–4] with the former one being dominant for heavy charged Higgs bosons $m_{H^\pm} \gtrsim m_t$ and the latter one for light ones $m_{H^\pm} \lesssim m_t - m_b$. Recently a new method for matching the differential cross-sections for the two production modes has been developed [5] resulting in a significantly improved discovery potential in the transition region $m_{H^\pm} \sim m_t$ [6].

A complementary production mode of charged Higgs bosons is in association with W -bosons. Although the production cross-section [7, 8] is large, an earlier study [9] using the hadronic charged Higgs decay, $H^+ \rightarrow t\bar{b}$, came to the conclusion that the signal is overwhelmed by the $t\bar{t}$ background. Here we report results of our study [10] of the prospects of using instead the $H^+ \rightarrow \tau^+ \nu_\tau$ decay together with $W \rightarrow 2$ jets.

The dominant production mechanisms for $H^\pm W^\mp$ at hadron colliders are $b\bar{b}$ annihilation at tree-level and gluon fusion at one-loop-level. In this study we focus on the parameter region with intermediate H^\pm masses ($\sim m_t$) and large $\tan\beta$, where the decay $H^\pm \rightarrow \tau\nu_\tau$ has a large branching ratio and where the $b\bar{b}$ annihilation dominates.

We have implemented [11] the two processes $b\bar{b} \rightarrow H^+ W^-$ and $b\bar{b} \rightarrow H^- W^+$ as separate external processes to PYTHIA [12]. In principle, the implementation in PYTHIA makes a generation of the complete final state possible, but for this first study we have chosen to stay on leading order parton level. For the calculation of the MSSM scenario and the corresponding Higgs masses and the branching ratios of H^\pm we use FEYNHIGGS 2.2.10 [13]. For simplicity we

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Table 1. The effect of the different cuts on the integrated cross-section for background (σ_b) and signal (σ_s) in the m_h^{\max} scenario with $m_{H^\pm} = 175$ and 400 GeV for $\tan\beta = 50$.

Cut [all in GeV]	σ_b (fb)	σ_s (fb)	$m_{H^\pm} = 175$ GeV		$m_{H^\pm} = 400$ GeV		
			S	S/\sqrt{B}	σ_s (fb)	S	S/\sqrt{B}
Basic cuts	560000	55	4900	0.7	3.3	300	0.04
$p_{\perp\tau_{\text{jet}}} > 50$, $\not{p}_\perp > 50$	22000	25	2200	1.6	2.7	240	0.2
$70 < m_{jj} < 90$	1700	21	1900	5	2.2	200	0.5
$m_\perp > 100$	77	15	1400	16	2.1	190	2.3
$p_{\perp hj} > 50$, $p_{\perp sj} > 25$	28	9.3	840	17	1.5	135	2.6

only consider hadronic decays of the τ -lepton, $\tau \rightarrow \nu_\tau + \tau_{\text{jet}}$ and these decays are performed using the program TAUOLA [14] in order to properly take into account the spin effects. The resulting signature of the signal is thus: $2j + \tau_{\text{jet}} + \not{p}_\perp$. The dominant irreducible SM background arises from $W + 2$ jets production which we have simulated with help of the package ALPGEN [15] again complemented with TAUOLA to perform the τ decay.

Our study is performed at parton level, without any parton showering or hadronisation. Instead the momenta of the jets are smeared as a first approximation to take these, as well as detector effects, into account. After smearing the following basic cuts are applied: $|\eta_{\tau_{\text{jet}}}| < 2.5$, $|\eta_j| < 2.5$, $\Delta R_{jj} > 0.4$, $\Delta R_{\tau_{\text{jet}}j} > 0.5$, and $p_{\perp\text{jet}} > 20$ GeV. We then apply the further cuts given in table 1 in order to suppress the background. Here $m_\perp = \sqrt{2p_{\perp\tau_{\text{jet}}}\not{p}_\perp[1 - \cos(\Delta\phi)]}$, with $\Delta\phi$ being the azimuthal angle between $p_{\perp\tau_{\text{jet}}}$ and \not{p}_\perp , is the transverse mass and $p_{\perp hj}$ ($p_{\perp sj}$) is the harder (softer) of the two jets. Although we have not simulated the reducible QCD background explicitly, the cuts $\not{p}_\perp, p_{\perp\tau_{\text{jet}}} > 50$ GeV are primarily included to take this into account. In order to get an estimate of the sensitivity due to this choice we have also used an alternative set of harder cuts, $\not{p}_\perp, p_{\perp\tau_{\text{jet}}} > 100$ GeV.

Here we only report results in the m_h^{\max} scenario, for which we have used $\mu = 200$ GeV, $M_{\text{SUSY}} = 1$ TeV, $A_t = A_b = A_\tau = 2$ TeV, $M_2 = 200$ GeV, and $m_{\tilde{g}} = 800$ GeV. The resulting signal cross-sections for $\tan\beta = 50$ and the two masses $m_{H^\pm} = 175$ and 400 GeV are given in table 1 together with the irreducible SM background. The resulting number of events and the significance S/\sqrt{B} have been calculated using an integrated luminosity of 300 fb^{-1} and a τ detection efficiency of 30%.

The m_{H^\pm} and $\tan\beta$ dependence of the cross-section after all cuts of table 1 are shown in figure 1 as solid curves whereas dashed curves denote the cross-section for the harder cuts $p_{\perp\tau_{\text{jet}}}, \not{p}_\perp > 100$ GeV. The left plot is for $\tan\beta = 50$ whereas in the right plot we have used $m_{H^\pm} = 175$ GeV (400 GeV) for the solid (dashed) line. The horizontal lines indicate the cross-section needed for $\frac{S}{\sqrt{B}} = 5$, corresponding to $\tan\beta \gtrsim 30$ if $m_{H^\pm} = 175$ GeV and $150 \text{ GeV} \lesssim m_{H^\pm} \lesssim 300 \text{ GeV}$ if $\tan\beta = 50$ with the softer cuts $p_{\perp\tau_{\text{jet}}}, \not{p}_\perp > 50$ GeV, whereas with the harder cuts $\tan\beta$ has to be larger than at least 50.

Figure 2 shows the resulting m_\perp distribution for $m_{H^\pm} = 175$ GeV as well as $m_{H^\pm} = 400$ GeV in the case $\tan\beta = 50$ compared to the background after all cuts in table 1 have been applied. In the high mass case the harder cuts $p_{\perp\tau_{\text{jet}}}, \not{p}_\perp > 100$ GeV are used giving $S/\sqrt{B} = 3.2$. Applying an upper cut $m_\perp < 200$ GeV ($m_\perp < 500$ GeV) for $m_{H^\pm} = 175$ GeV ($m_{H^\pm} = 400$ GeV) only marginally improves S/\sqrt{B} from 17 (3.2) to 19 (3.3). In the same figure we also see that the harder cuts create a fake peak in the background. Finally, using the harder cuts $p_{\perp\tau_{\text{jet}}}, \not{p}_\perp > 100$ GeV the significance for $m_{H^\pm} = 175$ GeV and $\tan\beta = 50$ is reduced to $S/\sqrt{B} = 3.1$. However, in this case using an upper cut $m_\perp < 200$ GeV is beneficial leading to a significance of $S/\sqrt{B} = 6.4$. For more details we refer to [10].

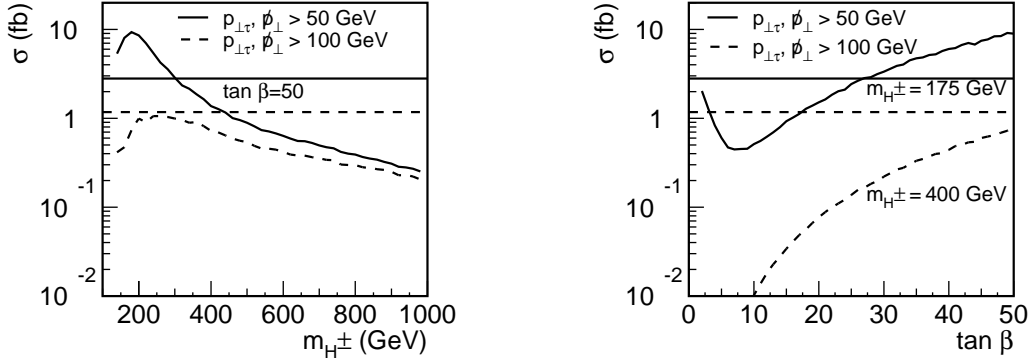


Figure 1. H^\pm mass and $\tan\beta$ dependence of the integrated cross-section in the m_h^{\max} scenario. Solid curves are with all cuts of table 1, and dashed curves are with the harder cuts $p_{\perp\tau_{\text{jet}}}, \not{p}_\perp > 100$ GeV. The horizontal lines correspond to $\frac{S}{\sqrt{B}} = 5$.

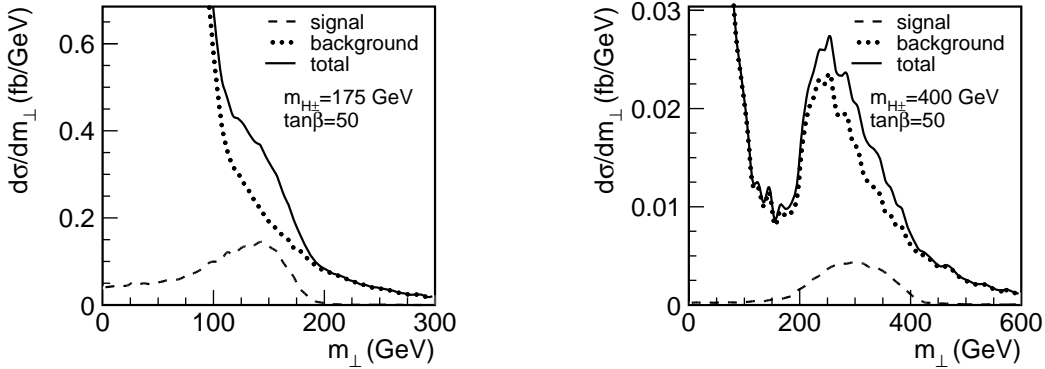


Figure 2. The m_\perp distribution for the signal (dashed) in the m_h^{\max} scenario with $\tan\beta = 50$ and $m_{H^\pm} = 175$ GeV (left) as well as $m_{H^\pm} = 400$ GeV (right) together with the background (dotted) with all cuts of table 1 (for $m_{H^\pm} = 400$ GeV the cuts $p_{\perp\tau_{\text{jet}}}, \not{p}_\perp > 100$ GeV are used).

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